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Understanding researchers' strategic behaviour in knowledge production: a case of social science and nanotechnology researchers

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Introduction

Research universities play a key role in today's economy by being providers of highly specialised knowledge and professionals. Both the produced knowledge and graduates are transferred to society and add to the competitive advantages of single companies as well as whole countries. To fulfil their missions and to remain innovative and competitive in the changing scientific landscape, universities face the challenge of managing and leading highly educated and autonomous professionals – researchers organised around very diversified knowledge domains or scientific disciplines with distinct organisational cultures, goals and strategies. We address this challenge by analysing the behaviours of researchers, which will help scientific leaders in developing strategies and policies relevant for the variety of behaviours.

The ways researchers produce knowledge and collaborate differ between scientific disciplines (Linton, Tierney and Walsh, 2012; Sabharwal, 2013). To date, the studies that have compared scientific fields have looked at metrics, i.e. hard indicators of knowledge production. Wanner (1981) and, more recently, Jaffe (2014) observed that the number of published papers was higher in the natural sciences than in social sciences. Jaffe (2014) also reported that natural science researchers tend to publish with more co-authors and tend to receive more citations than social science researchers. However, the differences are also seen in the distinct ways researchers organise their research, resulting from research traditions and the ways of working in these academic fields. For instance, in the natural sciences, collaboration is crucial for conducting complex experiments in which knowledge from various domains is often necessary and must be exchanged (Ziman, 1991). It is reasonable to expect that organisational settings and cultures lead to differences in the strategies researchers develop when producing knowledge between academic fields, because knowledge management strategies accommodate organisational climate and culture (McDermott and O'Dell, 2001; Liebowitz, 2008).

Knowledge production and dissemination has changed over the past few decades, and now take place in a distributed network of heterogeneous actors. It is becoming *socially robust*, applicable knowledge oriented to solving specific problems, with the increasing involvement of the environment: government, industry in academic research as well as in firms' R&D (Gibbons *et al.*, 1994; Hessels and Van Lente, 2008). The changes in the science system have impacted on the ways researchers produce knowledge and organise their research in different disciplines. To conduct relevant research, compete in the research market, and comply with the demanding performance measures universities have taken, researchers need to think strategically about their research and the dissemination of research results and to develop strategies to deal with external environments (Wilts, 2000; Leisyte, 2007; Teelken, 2012; Puciarelli and Kaplan, 2016). One of the strategic choices they make concerns establishing collaborations with both peers and industry (Bozeman and Corley, 2004). In their literature review of research collaborations, Bozeman, Fay and Slade (2013) acknowledge that collaboration increases researcher productivity. Yet these collaborations are costly and require the allocation of many resources (Hagedoorn *et al.*, 2000; Sonnenwald 2007). Researchers in various disciplines make different strategic choices, often depending on the availability of resources and the access to them, and therefore exhibit different strategic behaviours. We understand strategic behaviour as the long-term actions of acquiring and allocating resources and making decisions to attain goals (Bingham *et al*., 2014; David, 2011). Strategic behaviour thus always relates to goals – in this case, knowledge production goals.

Understanding the contexts of different fields in an organisation helps research managers to set research expectations and to assess researchers for promotion (Linton *et al.*, 2012); at the same time, it is crucial for research policy-makers when designing policy instruments (Kuhlmann *et al.*, 2007; Bonaccorsi, 2008). We focus on researchers' strategic behaviours, reflected in their choices when producing knowledge, and compare these behaviours in two scientific fields. We analyse conditions that lead to researchers' choices: the exchange of resources such as knowledge, skills and other research resources, and autonomy while making decisions when producing knowledge. This will result in a set of best practice conditions in knowledge production by researchers that can be integrated into internal policies by university and group leaders.

Knowledge production

Researchers seek to share their research results with the academic community as part of the academic ethos and owing to their primary goals (Merton, 1957). Research institutes and universities encourage their researchers to create more knowledge in order to increase their own competitiveness and innovativeness. Various factors increase scientific productivity. Personal interests seem to be an important factor (Ramsden, 1994) but, more often, external factors such as department characteristics (including research facilities, intellectual stimulation and motivation) (Allison and Long, 1990; Carayol and Matt, 2004; Louis *et al.*, 2004), internal management tools (such as communication, supervision, rewards system, co-ordination and research evaluation practices) (Van der Wijden *et al.*, 2008), entrepreneurial leadership with a strong network (Harvey *et al.*, 2002) and human resources (Harvey *et al.*, 2002; Crespi and Geuna, 2008) positively influence research outputs. The departmental environment might substantially help especially young researchers in their careers to build their number of publications (Ramdsen, 1994; Van der Wijden *et al.*, 2008). Therefore, it is important to consider knowledge production management.

These external factors all seem to have a common denominator: resources need to be allocated to perform research. The basis for all resources shared between researchers is – both explicit and tacit – knowledge. A study on UK academics reveals a positive attitude to knowledge-sharing among researchers (Fullwood, Rowley and Delbridge, 2013). Furthermore, this study shows that researchers share knowledge on research and on teaching rather than on university processes. Access to knowledge is seen as a primary driver for establishing collaborations between researchers (Beaver, 2001; Heinze and

Kuhlmann, 2008). Research has revealed that collaboration between researchers largely increases their productivity (e.g. Lotka, 1926; Price and Beaver, 1966; Zuckerman, 1967; Pao, 1982; Pravdic and Oluic-Vulovic, 1986; Allison and Long, 1990; Lee and Bozeman, 2005; Crespi and Geuna, 2008; Abramo, D'Angelo and Di Costa, 2009) and the impacts of their papers (Jones, Wuchty and Uzzi, 2008). Over the past few decades, the number of collaborations between researchers has increased (Abramo *et al.*, 2009). Among other reasons, the scarcity of available resources (e.g. Ziman, 1994, 2000), combined with the increasing number of multiple discoveries owing to the increasing number of researchers working on the same problems, as well as multidisciplinarity, drive researchers to collaborate (Katz and Martin, 1997). Hard sciences such as nanotechnology increasingly require large and expensive equipment and instrumentation that cannot all be obtained by one research group or even one institute.

Research collaborations vary in forms from informal communication to formal working together that often results in the publication of research results (Kats and Martin, 1997; Bozeman *et al.*, 2013). Most of the time, researchers share tacit knowledge via communication, lab experiments and writing papers. More experienced researchers pass their know-how on to their collaborators, often their PhD candidates. This knowledge-sharing type is most common, since according to Bozeman and Corley (2004), researchers tend to work with people from their own group. Thus, knowledge-sharing does not imply an end product such as a scientific paper or a patent, just like research collaboration does not necessarily imply a result.

As Kats and Martin (1997) pointed out, while a published paper is just a partial indicator of collaboration, it does have measurement advantages. Thus, most studies focus on collaboration understood as *co-authorship* (Bozeman and Corley 2004; Bozeman *et al.*, 2013). Many of these studies describe and explain research collaboration (its organisation, attributes and outcomes) (for an overview, see Bozeman *et al.*, 2013), and take for granted resource-sharing between co-authors, while research collaborations are costly and require the allocation of many resources (Hagedoorn *et al.,* 2000; Sonnenwald 2007). We expand on this by focusing on the need to share resources and on the decision-making regarding these resources and the knowledge production process.

Strategic positioning theory

To improve their competitive positions and expand research capabilities, researchers seek access to research resources such as knowledge and expertise, research equipment, instrumentation and financial resources (Heinze and Kuhlmann, 2008; Jeong, Choi and Kim, 2014). In the literature, the sharing of heterogeneous resources is seen as a necessary condition for any alliance (Kale and Singh, 2009), including a research alliance. Wilts (2000) stresses the importance of researchers' dependency on financial resources from economical and political actors. Resources in research usually refer to human capital (mainly knowledge and skills) and social capital (e.g. Price and Beaver 1966; Van Rijnsoever e *et al.,* 2008). External resources such as funding are seen as opportunities for new initiatives (Auranen and Nieminen 2010). Access to resources is the primary driver of establishing collaborations (e.g. Leisyte, 2007) and is therefore expected to result in higher knowledge production. Because engaging in a collaboration requires the allocation of time and other resources and involves sharing in the decision-making, the choice to engage in a relationship that eventually might help researchers to attain their goals of increased knowledge production is a strategic choice (Bozeman and Corley, 2004).

Relationships between researchers are often established to work on a project and can be seen as a temporary, project-based integration of actors with the aim to create value. In such integrations, management should consider not only resource-sharing but also that every partner will seek to retain as much autonomy and decision-making as possible.

Based on these arguments, we make use of strategic positioning theory (Kurek, Geurts and Roosendaal, 2007), which allows us to analyse researchers' strategic behaviour in relation to their environment (i.e. other researchers). Strategic behaviour refers to choices researchers make concerning knowledge production that allow them to attain their goals. Strategic positioning theory takes its main idea from the theory of integration of two or more organisations (Haspeslagh and Jemison, 1991). We adapted the original model to a level of individual researchers, as researchers are not organisations and control fewer resources than complex organisations. However, individual researchers also have goals, develop strategies and allocate resources to attain these goals. According to Haspeslagh and Jemison (1991), when integrating to create value, organisations have a certain need for interdependence (resource-sharing) and a need for organisational autonomy. Depending on the combination of these needs, the authors distinguish between four integration types and propose strategies that fit the goals of merging organisations. These two concepts, the need for interdependence and autonomy, were adjusted to the settings of individual researchers, albeit part of a department or an institute. Strategic positioning theory states that, in relationships, researchers express their need for strategic interdependence (defined as the sharing of heterogeneously distributed research resources and competences necessary to conduct research) and the need for organisational autonomy (defined as making decisions about research, research directions, research strategy and culture within the boundaries of the organisation that researchers are part of). Organisational autonomy refers to the autonomy of individuals within an organisation. Researchers are specific types of professionals: they strive for maximum autonomy in the pursuit of their goal – knowledge production (Merton, 1957; Fullwood *et al.*, 2013). Autonomy is tightly connected with academic identity (Henkel, 2005). This norm and value often drives researchers to remain in academia. Further, making decisions regarding research directions affects a researcher's reputation, which is an important aspect of building a successful career in science. Trevelyan (2001) found that molecular biologists are most satisfied with their job when their group leader is involved in their work yet does not set research directions. In other words, researchers' job satisfaction is high when their superiors are involved in their work, i.e. control the process yet give them autonomy to set research directions.

It has been acknowledged that relationships between research organisations and their external environments are shaped by the autonomy levels researchers have in setting research goals (Wilts, 2000). Different response of researchers to the external pressure on goals shape research strategies (Wilts, 200).

Even though *academic freedom* often refers to the relationship between researchers and society (e.g. funding agencies or industry), we use the definition of *academic autonomy* as “the right of staff in higher education to determine the nature of their work” (Neave, 1988, p. 43) and “autonomy to select problems and the means to solve them” (Varma, 1999, p. 23). In the literature, *researcher autonomy* is defined as freedom from influence of the environment, external pressure for instance in formulating tasks (Dill, 1958), “autonomy to control sufficient resources” (Collin, in Whitley, 1984, p. 12-13) and “self-governing in deciding about research, research goals and directions” (Kurek *et al.*, 2007, p. 503). Autonomy “depends on strategic choices to such factors as location, markets to be served or products to be made” (Aharoni *et al.*, 1978, p. 949). Sociologists of science used to distinguish between *pure science* and *applied science* on the basis of the autonomy researchers have in choosing research directions (Sutton, 1984). Recently, the meaning of *academic freedom* has changed from the freedom from external influences to “the power to manage multiple relationships” (Henkel, 2005, p. 170), and now includes collaborations with researchers. Applied science can also be autonomous. Organisational autonomy accounts for researcher decision-making in relationships with others and refers to organisational aspects of knowledge production, as we will outline in the measurement section.

The dimensions of interdependence and autonomy should always be observed in relation to researcher goals. The extents of interdependence and autonomy are not desired but are deemed necessary in order to attain goals. Researchers in relationships with their environment often need to give up some autonomy and need to accept interdependence in order to attain their goals. Strategic goals are conditioned by a researcher’s situation as a member of the science system. Researchers entering the science system agree to the knowledge production as this system’s overall goal, but also have personal goals, for instance, the type of career they aspire to: science, industry or research management.

Strategic positioning theory asserts that there are four researcher strategic behaviour types: mode0, mode1, mode2 and mode3 (see Figure 1). These modes, which are characterised by various combinations of the need for strategic interdependence and the need for organisational autonomy, are ideal types in the Weberian sense. In practice, they are continuous because the dimensions are continuous.

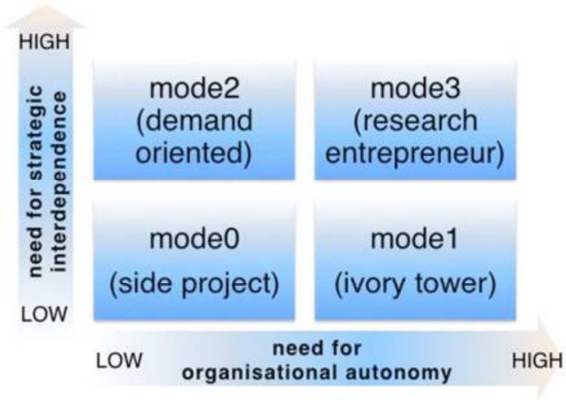

Figure 1 Researcher behaviour modes (adapted from Kurek *et al.*, 2007)

Mode1 (ivory tower) researchers have a strong need to direct research but without explicit resources from others; they don't need them in order to produce knowledge. Mode2 (demand-oriented) researchers are driven by delivering on specific research goals set by their environments, that is, any of the stakeholders involved in research (e.g. a firm or funding agency that is financing the research). These two modes resemble mode1 and mode2 proposed by Gibbons *et al*. (1994). The difference is that the modes we present allow for an analysis of the behaviour that can be used for predicting knowledge production (as we have shown elsewhere, Zalewska-Kurek *et al.*, 2010), while Gibbons *et al.*'s (1994) mode1 and mode2 are purely descriptive.

Mode3 (research entrepreneurs) researchers create demand for their scientific products. They have a high need for resources from their environment and a high need to make their own decisions about research.

The mode0 (side-project) researcher is a special behavioural case. In the original model by Haspeslagh and Jemison (1991), this behaviour type is seen as *no integration*, since the only relationship between two organisations is financial. Researchers behaving in mode0 do not need resources from others or a need to express their autonomy. There is no relationship in the strategic sense. These researchers might help others to produce knowledge, but they don't need them for their own performance.

We use strategic positioning theory to analyse knowledge production strategies expressed by researcher behaviour modes.

Sample and data collection

The data for this research were collected at a Dutch research university. While the Dutch scientific system is small, Dutch researchers are very productive, with a high global share of knowledge production (OECD, 2014). Dutch researchers also actively participate in various international collaborative research programmes (OECD, 2014). The main reason to choose this particular university was the combination of technical, behavioural and social sciences and, resulting from that, some visible differences in publication output, resources as well as size of the research institutes. This university has a number of research institutes and educational schools, to separate their budgets and management. The institutes and schools report to the university. We selected two research institutes that represent two academic fields: nanotechnology and the social sciences. The same context for these academic fields – both national and institutional – allows us to compare their strategic behaviours and choices within a given context. Even though the institutional context is the same, these two institutes differ concerning access to resources, the intensity of resources used and size. The nanotechnology institute is large and internationally renowned, with 500 employees, of whom 275 are PhDs or post-Docs. The institute's scientific fields include physics, electrical engineering, chemistry and mathematics. It acquires 60% of its revenue competing for external sources, and was chosen owing its competitive environment (national and internationally). The social sciences institute is a smaller institute, with 104 full-time equivalent staff members (at the time of the study) conducting research in public governance, entrepreneurship research, business administration, health systems and environmental studies. Its researchers earn most of their revenue from education programmes. The university is embedded within the local economy by its connections with industrial stakeholders and entrepreneurial activities.

We gathered the data from interviews and supported these by management data from the institute. Of the researchers, 43 responded positively to our invitation to be interviewed. We conducted 27 semi-structured interviews with nanotechnology researchers and 15 with social sciences researchers. Excluding preparation time, the interview duration was between approximately 1 hour and 1.5 to 2 hours.

The sample reflects the diversity of researchers at the two institutes: the researchers vary concerning their scientific positions (from PhD candidates, who are early career researchers in the Netherlands, to full professors) and managerial positions (group chairmen and scientific directors). The sample is sufficiently diversified, since we reached the saturation necessary for the exploratory purpose of this study. The respondents were positioned in all the modes, reflecting the variety of needs for strategic interdependence and for organisational autonomy. The social sciences sample was more heterogeneous than the nanotechnology sample, because the former institute represents more heterogeneous knowledge domains. We did not strive for statistical generalisability, but analytically analyse the differences in strategic behaviours when producing knowledge in order to contribute to the existing literatures on knowledge production and knowledge management.

Measuring researchers' strategic behaviours

To measure the strategic behaviour of researchers when producing knowledge, we asked questions regarding their choices when writing scientific papers. We selected three peer-reviewed journal papers (or less if they did not publish three) of each interviewee and asked questions about the writing of these papers, resources shared with co-authors and decisions made during the process. The publications needed to represent different researcher roles (indicated by a place on the authors list) and the variety of (institutional and international) co-authors. We chose papers that present a spectrum of co-authors of a researcher, such as PhD candidates, supervisors and researchers from other universities and institutes. To explore the contexts in which the interviewees did their research, we asked what motivates them to make their research results public and about their perceptions of the competition in their field. Such competition is seen as increasing, putting pressure on researchers (Teelken, 2012). Further, we reconstructed the researchers' needs for strategic interdependence and for organisational autonomy by observing the organisation of making research results public and the acquisition of scientific information – knowledge dissemination and knowledge acquisition.

Strategic interdependence

To measure the interdependence of researchers in the writing process, we asked them about their and their co-authors' roles in the writing: *Why did you publish with your co-authors? What were your and what were their contributions to these articles?* In answering questions on the authoring process, the researchers indicated their inputs to their articles and how co-authors contributed. This measured which resources are shared: knowledge, skills, time, funding, etc.

In science, researchers share (knowledge dissemination) their research results in order to acquire scientific information from others (knowledge acquisition). Thus, we analyse both knowledge strategies: acquisition and dissemination. We analyse the extent to which researchers rely on their colleagues when acquiring information. We asked questions about how and when they acquired information, about who they rely on when remaining up-to-date with recent developments, and about what sources of information they used. We also asked why they attended conferences; the answers indicated that this is an important way to remain up-to-date.

Thus, we measured the need for strategic interdependence concerning:

- Dependence on colleagues in writing articles.
- Dependence on information sources in acquiring scientific information.

Answers about the writing process indicated what researchers' inputs to the mentioned articles were and how other co-authors contributed. Researchers writing articles without help from other researchers are less dependent on others than researchers who do not write the articles they co-author. They often answered that they are involved in a discussion on an outline and in a final draft. Researchers writing an article usually spend more energy on it than researchers who comment on such an article. Researchers who publish alone (without any other researcher) are independent of others in this regard, and we coded their behaviour as a low need for interdependence. Some researchers are not directly involved in the writing process, but provide facilities and acquire financial resources for research. Their input is connected with the research process, but not with making the research results public. We coded their behaviour as having a high need for interdependence. A high need for interdependence is also present when researchers do not write articles but only comment on drafts without correcting them.

While making results public is often a joint effort, the acquisition of information is an individual activity. However, researchers rarely acquire information in isolation from their colleagues, who are sources of information. For instance, we asked, *How do you learn about new developments in your field?* The researchers who answered that they learn about new developments via *the Internet, various databases, by scanning or reading scientific or professional journals, and/or from the articles sent by editors for review* show a low need for interdependence. They do desk searches, and do not depend on colleagues. Involving other researchers, indicated by such answers as *at conferences, meetings with other researchers, from mailing groups, and/or from my candidates, colleagues and collaborators* increases the need for dependence because the researchers rely on information communicated and selected by other people.

Organisational autonomy

Organisational autonomy, understood as governance, includes all organisational decisions in research; in our case here: setting research goals, acquiring research funds, decisions on with whom to collaborate with, on which resources to acquire from whom, and decisions concerning making research results public and concerning acquiring scientific information.

The need for organisational autonomy is observed in specific decisions researchers take in knowledge production; for instance:

- Decisions about what to write in an article.
- Decisions about where to submit an article.
- Decisions when an article is ready for publication.
- Decisions about which relevant articles to include or cite in articles.
- Decisions about which scientific information to acquire.
- Decisions about research goals.

Researchers have high autonomy if they have influence and power over a paper's content (on the line of argumentation, how to present the content, what to include and why), the process and on decisions about where to submit a paper. Researchers who let others decide on the quality of work (when an article is ready for publication, choosing relevant articles to be included in an article and where to submit an article) have low researcher autonomy in this situation.

Decisions are also measured in answers to the question, When your PhD candidates encounter problems in their research and ask you for help and you do not know an answer, do you try to find out? How do you do this? The answers to this question indicate researchers' behaviour when collaborating with their closest collaborators specifically when acquiring scientific information. Researchers who are influenced by their closest collaborators (e.g. PhD candidates or collaborating colleagues) have low autonomy in such situations because they need to allocate time and other resources to a specific activity. They are influenced if they search for specific information when a colleague suggests that a specific problem must be solved. If a researcher refers PhD candidates or colleagues to specific researchers or recommends that specific literature be acquired, he or she has high autonomy, because he or she does not perform the search but influences other researchers' acquisition of information.

Another measure is checking for publications. Researchers were asked, If you come up with an idea for how to solve your research problem, experiments, etc., do you ensure that something similar has not already been published? A researcher who does not have to check if something similar was published because his or her co-author does this (first authors, colleagues) is not autonomous in selecting – his or her co-authors are responsible and influences this. If a researcher checks whether something similar has been published, he or she is considered highly autonomous in this aspect of selecting scientific information.

Modes of strategic behaviour

Researchers gave multiple answers to the open-ended questions, which were coded in a binary system (0 = *not observed*, 1 = *observed*) to classify researchers into different modes. The separate indicators were coded as low needs (-1) or high needs (1). We first computed overall strategic interdependence and organisational autonomy. We computed strategic interdependence as the mean of the partial positions in dependence on colleagues in writing articles and dependence in acquiring scientific information. We computed organisational autonomy as the mean of autonomy in choosing journals, writing autonomy, autonomy in assessing when an article is ready for publication, autonomy in selecting journals for publication, autonomy in choosing references and autonomy in the acquisition of scientific information. *Interdependence* and *autonomy* are interdependent. We calculated the modes as a combination of interdependence and autonomy. The final modes presented in the results section are the average values of three relationships, as indicated by the papers discussed in the interviews. We analysed the interviews to compare different strategic behaviour modes.

Results

Context of strategic behaviour

The first most visible difference is in the number of papers published per year by researchers. An analysis of the peer-reviewed journal papers shows that the distribution of knowledge production (Figure 2) in both samples shows exponential decay and fits Lotka's law (1926): about 60% of the sample researchers published about one article a year. Nanotechnology researchers tended to publish more papers per researcher per year than social science researchers. The majority of the sample nanotechnology researchers published between 1 and 5 papers per year, while 40% published more than 5 papers per year. Most social science researchers published between 1 and 2 papers per year.

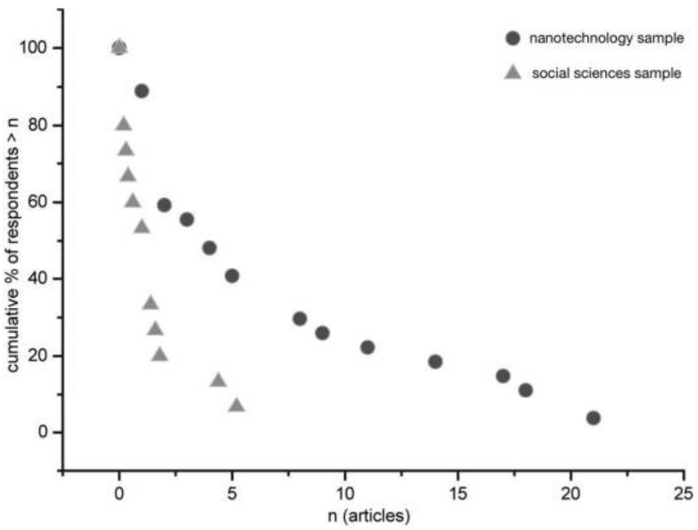

Figure 2 The cumulative distribution of the number of papers published by researchers per year

This indicates that these two samples cannot be analysed together in relation to the absolute number of papers, and conclusions need to be drawn with care. However, we analysed the strategic behaviours that lead to attainment of knowledge production goals, and these can be analysed in the same way to point out similarities and differences. We outline the organisational context and account for the differences in the contexts (e.g. the availability of research grants) in the discussion section.

We asked the interviewees what motivates them to make their research results public. Three primary motives emerged from the answers: external pressure, knowledge-sharing and recognition. These motives were usually combined in the researchers' answers (Figure 3) in the entire sample. The main reasons were *knowledge-sharing* and *external pressure*. The latter refers to the expectations to publish owing to the requirements of the research group or the science system. Some researchers mentioned that they had to show that public money was spent well. The pressure was present for PhD candidates who even said, *"I must publish because my supervisor wants me to do so"* (n12). The knowledge-sharing motive is perceived by some respondents as an 'idealistic' reason; some even used this word. It was often a first answer to this question and was often followed by *external pressure* or *recognition*. From these responses, we conclude that the knowledge-sharing motive is something of a cliché. About one third of the researchers in the sample said they publish because they want to share knowledge or want to gain recognition in their scientific domain and owing to external pressure. A small minority of interviewees publish only because they want to be recognised as authors of their discoveries and want to share knowledge.

In our view, an interesting observation is that the sample PhD candidates will seek to get their degree and will then leave academia for industry. This was mostly the case in the nanotechnology sample. These PhD candidates saw a PhD as an education step that would help them in their career in industry. They did not strive for a high publication rate, and the reason for publication was *external pressure*. This was not the case for researchers who want to stay in the academic world and were already an assistant professor or higher. Senior researchers seemed to make a deliberate choice to make their career in science, and have internalised the social rule regarding publishing. They saw advantages of making research results public to their peers – first, to advance knowledge; second, to be recognised for their scientific achievements. Such an attitude was seen in their answers to the question, *Why do you publish?* For instance, *"because research is less relevant if you don't publish"* and *"show that the work you do benefits others" (n10).*

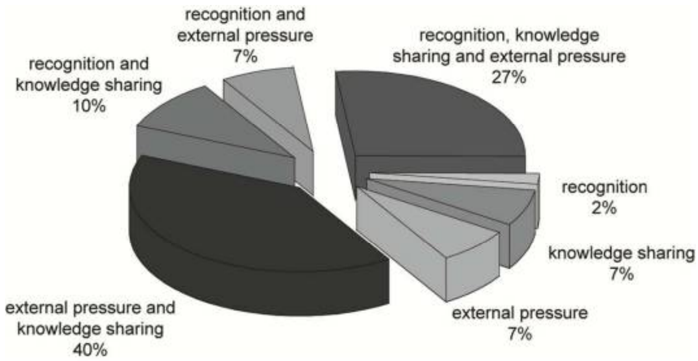

Figure 3 Motives to publish research results (n = 43)

We have also analysed the competition within the two fields. Following the study by Hagstrom (1974), who discovered that 60% of his respondents among physics and biology scientists faced the situation that someone else had published a solution to their research problem at least once – we asked, *Have you ever experienced a situation that you are working on a problem and then you find that the solution you are about to deliver and publish has been published by other scientists?* Based on the answers, competition appeared to be higher in nanotechnology than in the social sciences. It did not happen often, since researchers tried to find a niche, but it still happens. One nanotechnology researcher told us that, at a conference he attended, someone presented similar results to his, concluding that *"I had to publish as quickly as possible to be first in my field"* (n11). None of the social sciences researchers reported such a situation. They said there always would be a difference in term of topics or approach.

Modes of strategic behaviour

We did a qualitative analysis of the strategic behaviours of researchers and provide insights into what different modes mean in practice and how we can interpret them based on strategic positioning theory.

We observe that **mode 3 (research entrepreneurs)** researchers do not always write first drafts themselves. On average, their input is rewriting or editing what their co-authors have written. They are often involved in discussions on outlines of papers and in final drafts. Thus, they are highly dependent on the researchers they publish with – usually the scientific staff in their research groups or collaborative groups. Researchers with a moderate need for interdependence more often write articles and only ask for comments.

High dependence is also indicated by the extent to which a researcher relies on his or her colleagues in acquiring scientific information. A research entrepreneur relies on information they receive from colleagues. This means that they use other researchers as a primary source of scientific information, for instance by asking colleagues about new developments in a scientific domain. Highly interdependent researchers also acquire scientific information from colleagues from their scientific domain, either by contacting them directly or by meeting them at conferences.

Some researchers are not directly involved in the writing process. We do not exclude them from the sample if they provided facilities and acquired financial resources for research. Their inputs are connected with the research process, specifically in the organising and managing the research process, but not with publishing the results of the research process. They are highly dependent on their co-authors when writing papers. In the literature, they are defined as *patrons* (Bozeman *et al.*, 2013), but we consider their role in knowledge production to be strategic since, by getting funding, they set the overall direction for a project.

Mode3 researchers make decisions on what to submit and where to submit an article, and assess when the work quality is sufficient to be scrutinised by external reviewers. In terms of acquiring scientific information, research entrepreneurs are not influenced by others on what they should acquire and when. They influence the behaviours of others.

Mode1 (ivory tower) researchers do not depend on their colleagues when making research results public and when acquiring scientific information. This does not necessarily mean that they work in isolation and that they do not ask for advice; it means that other researchers don't have a direct influence on their decisions. The interviewees rarely position themselves in an extreme or pure ivory tower. They make some decisions with the colleagues with whom they publish their research results. In principle, mode1 researchers don't depend on their colleagues in making research results public. They write and edit an article themselves and make autonomous decisions on what should be included and cited in articles, and when articles can be submitted to journals, and to which journals. Researchers who write their articles themselves are less interdependent on their co-authors' knowledge, skills and time, unless they publish with their early-stage PhD candidates and must spend more time teaching them how to write scientific articles.

When acquiring scientific information, mode1 researchers also remain autonomous and independent. They rely on colleagues less than research entrepreneurs, that is, they generally acquire information from the Internet, databases or scientific journals, and so on. Mode1 researchers are similar to research entrepreneurs in that they influence others' behaviour and are not influenced, for instance when checking if someone else has already claimed intellectual property to similar ideas or developments. Both research entrepreneurs and ivory tower researchers personally select these kinds of information.

Mode2 (demand-oriented) researchers are highly dependent on their colleagues, like research entrepreneurs, but unlike research entrepreneurs they are less autonomous. Mode2 researchers' inputs usually involve commenting on drafts written by other researchers. They are not the primary stakeholders in the writing process. They do not make autonomous decisions on what, when and where to published. They make such decisions jointly with other co-authors, or others make them. An example is a researcher who contributes to others' research by adding his or her expertise to a paper, but who is not responsible for the paper or for decisions about which journal it should be submitted to.

Demand-oriented researchers depend on their colleagues when acquiring scientific information and are also influenced by them, for instance by candidates asking for specific information that must be acquired.

Mode0 (side-project) researchers were only present in the nanotechnology sample. While these researchers do not establish strategic relationships with their colleagues when making their research results public, they do form relationships. The sample side-project researchers are very close to mode2 researchers though.

Comparing strategic behaviour between nanotechnology and social sciences researchers

Although the modes are not discrete, we present them in a table to show their distribution in the subsamples (Table 1). Table 1 does not show differences between researchers within the modes. The most frequent behaviour mode among the nanotechnology researcher sample is mode3. The nanotechnology researchers have on average a fairly high need for autonomy (75% of the interviewed researchers have autonomy higher than 0.5 on a scale of 0 to 1) in making research results public and acquiring scientific information, and have a high need for interdependence (about 65% have interdependence higher than 0.5 on a scale of 0 to 1). Extreme values of 0 or 1 have not been observed for either dimension. The distribution of modes is almost reversed in the social science sample, where researchers behave mostly in mode1, showing a lower need for interdependence and a higher need for autonomy.

Table 1 Distribution of modes of strategic behaviour

We present the primary behaviour differences between the two samples in Table 2. The most prominent difference between the nanotechnology researchers and social sciences ones was in the need for *strategic* *interdependence* – the former tend to share more resources. This was particularly visible in access to funding, research equipment and knowledge. Nanotechnology researchers had fairly specialised knowledge and needed to collaborate with other researchers to pursue innovative research across several disciplines, such as chemistry and physics. A researcher said: *"We involved new people who brought about better quality, and we could publish in a better journal" (n11).*

However, this does not mean that social sciences researchers did not need to share resources. They did so to a lesser extent, since their projects do not require large and complex research facilities or such diversified and interdisciplinary knowledge as the nanotechnology sample projects.

Table 2 Comparison of the need for strategic interdependence and the need for organisational autonomy in the nanotechnology and social sciences samples

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In both samples, researchers had a high need for *organisational autonomy*. Some respondents mentioned that they had returned from industry to academia owing to the freedom a university provides.

However, even with a high need for autonomy in both samples, we still observed some variation in the extent to which researchers in various career stages need autonomy and how they organise their research and develop their strategies. As noted, this depends on a researcher's goals. For instance, the PhD supervision and the PhD candidates' autonomy differed between the samples. In the nanotechnology sample, PhD candidates were hired for an existing project that had been acquired by an assistant professor or more senior researcher. Here, they were accountable to their supervisors, who were then accountable to the external funding agency or the firm financing the research project. It was in the supervisor's sole interest to ensure that the project would deliver its expected outcome. Thus, the goals and accountabilities of project leaders affected the ways PhD candidates were supervised. In the social sciences, this was not always the case. Sample social science PhD candidates seemed to have more autonomy in setting the initial research goals, since they were often hired for an 'open' project – they could propose the directions they wished to pursue.

Journal choice is a strategic choice, as indicated by researchers, because it affects researcher recognition. Interestingly, when asked about the 'dream' journals in which they would like to publish, the researchers indicated journals that address a specific audience, and not necessarily the best-known journals (e.g. *Science* and *Nature* for nanotechnology researchers). While the impact factor was an important criterion, it was not as important as the reader audience. In the social sciences sample, PhD candidates often proposed journals for their papers, although the decision was always discussed with their supervisors, who might have (dis)agreed with their proposals. In relationships with more senior researchers, the social sciences interviewees were highly autonomous in making decisions about the journal if they were the primary authors.

There was almost no difference between the samples concerning their information search behaviours. We only observed a difference between researchers in different career stages. Junior researchers remained up-to-date and regularly acquired scientific information from scientific journals to learn about the field and to get information for their research, while senior researchers used conferences as sources of information on what's happening in their fields. Senior researchers depended on their PhD candidates and colleagues when remaining up-to-date. They acquired information themselves when writing research proposals.

In summary, we observed tensions between remaining autonomous while working together and being interdependent on colleagues. This was particularly the case with researchers of the same rank.

Discussion

We have analysed the strategic behaviour of researchers in relation to knowledge production, expressed in behaviour modes. An understanding of such behaviour is necessary for scientific leaders to be able to manage diversified groups of researchers with own goals, strategies and organised in specific organisational cultures. The results of a qualitative empirical study of two scientific fields show that that there are large differences in the strategic behaviours of social science and nanotechnology researchers. Nanotechnology researchers behaved mostly in mode3, i.e. as research entrepreneurs, sharing resources and being highly autonomous, while social science researchers behaved mostly in mode1, i.e. the ivory tower (highly autonomous but without the need to share resources). We have seen that researchers are willing to give up some autonomy when it serves their goals, that is, when it increases their knowledge production. Nanotechnology researchers collaborated, i.e. they shared both explicit and tacit knowledge with researchers from various disciplines in the lab and when writing papers. This seemed more natural to them because the knowledge is often specialised, and they needed to collaborate with researchers from other domains in order to innovate. This argument is consistent with the analyses of publications by Leydesdorff and Rafols (2009) and Jansen *et al.* (2010), indicating heterogeneity within nanotechnology concerning the multidisciplinarity of topics. A possible explanation of social science researchers' low need for strategic interdependence is that they do not need to share expensive research facilities such as cleanrooms or specialised labs. Further, social scientists are not yet used to connecting various scientific disciplines in one research project.

What was common for the sample researchers from the two knowledge domains was the strong need for organisational autonomy. Clearly, the researchers enjoyed their autonomy and would choose employment that offered them much autonomy, as well as access to knowledge and facilities that would help them to do research. Indeed, autonomy and the opportunity to create new and innovative knowledge were often given as the reasons to return from industry.

As we have shown elsewhere (Zalewska-Kurek *et al.*, 2010), in a quantitative analysis, nanotechnology researchers are most productive in mode3. In this study, we qualitatively analysed the strategic behaviour modes, but have also seen that the most productive mode in the nanotechnology sample is the research entrepreneur. We cannot draw such a conclusion about social science researchers or about other disciplines or institutes, since we don't have data to do so. However, if we assume, based on the previous studies, that mode3 is the most productive mode in any field, the question is, *How do we create an environment that facilitates collaborative projects and resource-sharing?* This is an important challenge for research managers: *What are the obstacles for collaboration among social science researchers? What are the barriers to even greater knowledge-sharing?* Jaffe's (2014) study delivers a possible answer relating to the dynamics of disciplines. Jaffe indicates that the social sciences landscape is fragmented, and focuses on many isolated knowledge clusters and publishing in many more journals than natural sciences. This creates isolation within and among social sciences researchers (Jaffe, 2014).

The sample researchers shared publishing strategies, consistent with another study on biotechnology researchers (Leisyte, 2007) that target quality journals and often increase quantity of publications as a strategy to manage external tension from the research system. At the same time, the researchers differed in their needs for strategic interdependence as well as in their productivity and publishing habits. This observation is consistent with the arguments of McDermott and O'Dell (2001) and Liebowitz (2008) about organisational culture's influence on knowledge management strategies: difference in knowledge production result from differences in organisational cultures of knowledge domains. Further, differences in the dynamics of scientific disciplines lead to different ways to create knowledge, depending on a discipline's maturity (Whitley, 1984; Bonaccorsi and Vargas, 2010). As a young science, nanotechnology creates a turbulent environment (Bonaccorsi and Vargas, 2010) and is "intrinsically based on institutional complementarities" (Bonaccorsi, 2008, p. 307), that is, it requires heterogeneous knowledge, experience and competencies from researchers working in various institutional environments. Nanotechnology also values divergent knowledge to create new knowledge (Jansen, Van Görtz and Heidler, 2010).

This paper provides insights into the strategic behaviour modes that, as reported in the literature, have consequences for knowledge production. As discussed in our introduction, the literature reflects the differences between the two disciplines concerning knowledge production, acknowledges the differences in access to funding as well as in the nature of their research. However, the knowledge production modes are not discussed at the level of individual researcher behaviour. Mode1 and mode2 (Gibbons *et al.,* 1994) (Triple Helix) (Etzkowitz and Leydesdorf, 2000) and Mode3-Quadruple Helix (Carayannis and Campbell, 2009) describe the changes in the research environment and knowledge production, but do not provide analytical models to analyse researchers' behaviour. By analysing the need for strategic interdependence and the need for organisational autonomy, we contribute to the literature on relationships and alliances between researchers, and to the application of stakeholder theory to the research environment (e.g. Miller *et al.*, 2014).

This study has implications for theory, research management and research policy. For research organisations, this paper delivers an instrument for analysing knowledge production mechanisms within research organisations. If they have such knowledge about researchers' strategic behaviours in their institutes, together with the resulting knowledge production, research managers can create a suitable and comprehensive environment to enable the intended production of knowledge and can boost their institutes' innovativeness and competitiveness in the long term. From the perspective of the studied nanotechnology institute, researchers should strive to be dominantly entrepreneurial (i.e. mode3). In practice, this means creating and sustaining internal *research programmes* that serve as a framework for research while also letting researchers make their own decisions within the frames of these research programmes. However, other modes may also be possible or even desirable within an organisation. The high need for organisational autonomy indicates that researchers should decide on research directions. Management should balance different modes, resulting in the intended knowledge production by the institute and in satisfied employees. By managing the extents of researcher autonomy and interdependence to be commensurate with their strategic goals and the goals of the research institute, researchers and an institute can achieve what they seek to achieve. Strategic positioning theory can be used to direct researchers' behaviours by creating a comprehensive environment for achieving the goals of research institutes or policy-makers. Based on the results of both quantitative and qualitative studies, we propose the sharing of best practices from nanotechnology, because full adoption of the behavioural patterns considering the differences in the nature of publishing, funding and other institutional aspects will not be possible. *What can the social sciences learn from nanotechnology?* The fact that disciplines are heterogeneous, differ in dynamics, dependence on and availability of external funding, publishing habits and knowledge production strategies does not preclude research managers from applying similar management tools to increase collaboration, for instance, collaborative research programmes that strengthen knowledge exchanges and research facilities yet leave room for autonomous and innovative decisions regarding research directions.

For science policy, our results deliver yet another argument to support the assertion by Kuhlmann *et al.* (2007) and Bonaccorsi (2008) that one science policy does not fit all disciplines and that science policies don't always acknowledge differences between or changes within disciplines. These scholars assert that scientific disciplines are heterogeneous and should be dealt with by tailoring different policy instruments (i.e. funding criteria) to different disciplines. We have also observed that, despite its homogeneity concerning publishing habits and internal competitiveness levels, the nanotechnology institute was fairly heterogeneous concerning its researchers' strategic behaviours. In the social science institute, we observed even more heterogeneity concerning both publishing habits and behaviour. Thus, heterogeneity should be considered not only in terms of the number of papers published by researchers, but also in terms of the organisation of knowledge production. Clearly, more aspects than just productivity should be considered when setting research strategies.

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Mode	Distribution	
	Nanotechnology	Social sciences
Mode0	11%	-
Mode1	22%	66%
Mode2	11%	7%
Mode3	56%	27%

Table 1 Distribution of modes of strategic behaviours

Concept	Nanotechnology sample	Social sciences sample
The need for strategic interdependence (SI)	*In general, the need for SI in the nanotech sample is higher than in the social sciences sample.*	
Dependence when writing papers	Researcher diversity was greater in this sample; we counted 4 or 5 co-authored papers (some papers with more researchers involved). They were often from other universities.	Less diverse collaborators who mainly came from the same group or institute; less international paper collaborations. They network internationally, but this does not result in joint papers as often as in the nanotech sample.
	Researchers relied on other researchers' knowledge when doing research, particularly when doing experiments in the lab.	Researchers published papers on their own.
	This indicates high need for resource-sharing, particularly the knowledge and skills of people involved in research.	Professors publish mainly with their PhD students, because they indicate that they do not have time to write themselves.
	The affiliations of collaborators also indicate high diversity of resources (multidisciplinary knowledge, access to labs, joint application for funds).	Research in some domains (health studies) required more research resources, such as access to patients and specific knowledge about research techniques. Thus, they involved several researchers from various institutes. It was common to co-author a paper with more than two collaborators.
	We observe a presence of *strategic co-*	

	authors – researchers who do not write and hardly comment on some of their articles. They provided facilities and acquired financial resources for research. Their inputs connected with the research process rather than the writing. They were highly interdependent on researchers they publish with – usually scientific staff from their research group.	
Dependence on information sources	Especially senior researchers and professors were more dependent on PhD students when acquiring scientific information to remain up-to-date with recent developments. Some senior researchers indicated that they only search for scientific information themselves when writing a proposal.	Senior researchers were more dependent on their PhD students to remain up-to-date with the literature. They acquired information when they needed it.
The need for organisational autonomy (OA)	*The need for OA is fairly high in both samples. Our general observation is consistent with the literature and the anecdotal knowledge indicating that the higher a researcher's rank, the higher their autonomy.*	
Decisions about writing papers	The majority of professors involved in the writing process (i.e. they are not just strategic authors) discussed the papers heavily and influenced their contents.	There was much variety among senior researchers: some relied heavily on their PhD students and other colleagues when writing papers (PhD students proposed the outline, which was then discussed), and they only commented. *"I was deeply*

	Overall, nanotech PhD students seemed to have less autonomy than PhD students in the social sciences sample. Most of the time, nanotech PhD students formed part of bigger projects with clearly defined deliverables.	*involved in reviewing the paper. Some of my concepts were used" (soc13).* When published without PhD students, senior researchers wrote parts of the papers or even first drafts themselves.
	Almost all full professors in the sample said that they decided upfront where to submit their papers to. PhD students indicated that the *"professor decided for me" (n24).*	Most PhD students indicated that they proposed a journal to which their paper should be submitted.
	Supervisors often told their PhD students when to stop research and when to start writing papers; because of his experience, *"he knows what is good for a publication" (n24).*	It was up to the supervisors to take the decision to publish.
Decisions when acquiring scientific information	Professors rarely checked information, and junior researchers were mostly autonomous in this regard.	No difference from the nanotech sample.
Decisions on research goals	Professors set research directions when writing a proposal.	Senior researchers were very autonomous in setting research directions for their own research.
	Almost all PhD students and post-Docs came to projects with defined goals.	In relationships between supervisors and

	PhD students, the latter often first proposed or even defined goals and then discussed them with their supervisors.

Table 2 Comparison of the need for strategic interdependence and the need for organisational autonomy in the nanotechnology and social sciences samples

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